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Orlando, Florida, March 1-3, 1966

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As space missions involve increasing amounts of astronaut extravehicular activity, and even spacecraft operating in close proximity to one another, the likelihood of cryodeposition increases. This note considers the effects of cryodeposits on spacecraft thermal control systems from two points of view; first, the intentional use of cryodeposits as a means for beneficial modification of surface radiative properties, and secondly, the effect of deposition on the inner surfaces of a shadow shield array.

Before consideration of the effects of cryodeposits on thermal control systems, a few words of background are in order. The first in-flight observation of cryodeposit material was made by Astronaut Col. John Glenn during the flight of MA-6[1]. Col. Glenn observed luminous particles in the vicinity of his craft when emerging from the night side of the orbit. Because of the apparent size and luminosity of these objects, Glenn called them "fireflies". Subsequently, similar particles were observed by Astronauts Carpenter and Cooper. Carpenter [2] demonstrated that the particles could be generated from the exterior bulkhead of the craft itself; Cooper observed similar particles emanating from an attitude control thrustor. O'Keefe [2] suggests that the majority of these particles were crystallized steam. In the first case, the steam which crystallized resulted from the direct disposal to space of the water used in the spacecraft life-support system and in the second case, from the attitude control thrustor propellant H_2O_2. In addition to these flight observations, there have been laboratory observations of H_2O and CO_2 cryodeposits under high vacuum conditions. These observations have

been reported by Cunningham et al. [3] and Caren et al. [4]. At Lewis Research Center, J. T. Cassidy recently observed an H_2 cryodeposit. Thus, there is evidence to show that condensed gases can remain stable on a surface exposed to a space environment and, as a result, may possibly alter the radiative properties of surfaces that are critical to the thermal design of the spacecraft. This possibility is examined below.

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McConnell [5] has investigated the conductive heat transport within a nonopaque solid such as frost. The nonopaque solid (cryodeposit) covers the exterior surface of a cryogenic reservoir, such as a fuel tank, and is exposed to incident thermal radiation, as shown in figure 1. The analysis was made for several frost thicknesses and took account of the ability of the frost to lose heat by sublimation. Figure 2 presents the total heat transported to the substrate (fuel tank) as a function of cryodeposit depth. In this and succeeding calculations, the deposit is assumed to be H_2O for which the radiative properties are available. The total heat transport is the sum of the heat conducted by the deposit to the substrate plus the radiant heat transmitted through the deposit to the substrate, namely,

$$q_{tot} = q_{cond} + q_{rad}$$

This sum is nondimensionalized through division by the incident radiant energy. In figure 2, it is readily apparent that the presence of an H_2O deposit on a highly reflective surface has a detrimental effect, for the heat transport is thereby increased. For an optical thickness of 1, which for solar radiation corresponds to a frost thickness of about 33μ, the heat transport to a reflective substrate is increased by a factor of 8; whereas, the heat transport to the less reflective substrate is increased by only 2 percent. Furthermore, at an optical thickness of 5 (corresponding to a frost thickness of 0.15 mm), the heat transport to the less reflective substrate is decreased by 30 percent from the amount when no deposite is present. For optical thicknesses greater than 4, the heat transport is independent of substrate reflectance, the primary mode being conduction from the deposit. The total heat transport ratio apparently approaches a limiting value of 0.15. Thus, the presence of a deposit always increases the

heat transported to a highly reflective substrate ($\rho > 0.85$), whereas for a less reflective substrate ($\rho < 0.85$) the deposit may decrease the total heat transport. This may be significant for an initially reflective surface which becomes less reflective because of exposure to micrometeoroid impaction. In such an instance, a deposit produced either naturally or artificially could have the beneficial effect of decreasing the heat transported to the surface. On manned missions, the H_2O and CO_2 available as by-products of the spacecraft life-support systems could perhaps be used to produce such a deposit. Since the exposure time for impaction degradation is still subject to question, the importance of this problem is not yet clear.

A cryodeposit can also have a significant effect if it grows on an interior surface of a shadow shield array used to reduce solar heating of a cryogenic fluid. Several illustrative cases are presented in figure 3, wherein the calculated net radiant heat flux arriving at the cryoreservoir is shown for various cryodeposit locations. In these calculations, it was assumed that the deposit (e.g., H_2O) increases the emittance of an aluminum surface from 0.045 to 0.090. (As shown in [5], the actual overall emittance would be a function of deposit depth, and an emittance of 0.1 would correspond to a deposit depth of only 3μ.) Figure 3 shows that in those cases in which a deposit is present, the heat flux to the cryogen is increased by over 30 percent. This result indicates that provisions should be made for the avoidance of such deposits, if possible, or for the removal of deposits which do occur.

The preceding calculations show that the effects of cryodeposits on spacecraft thermal protection systems can be large, and that the effects can be either beneficial or deleterious. Spacecraft designers should, therefore, take steps to avoid such deposits where they may have an undesirable effect and perhaps to enhance their formation where the effect is advantageous.

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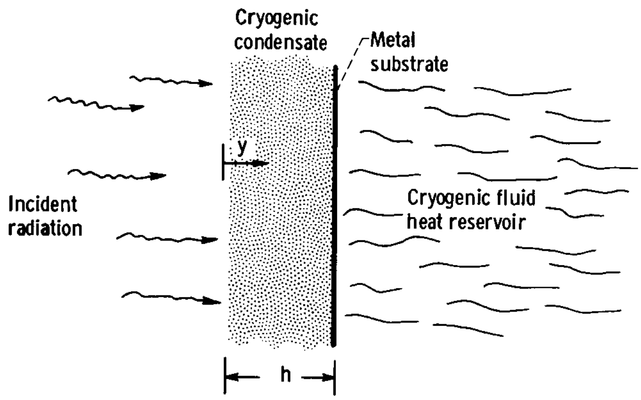


Figure 1. - Cryodeposit-substrate complex.

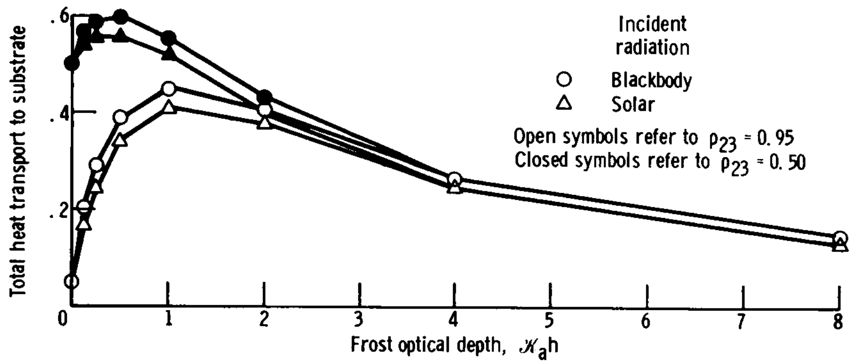
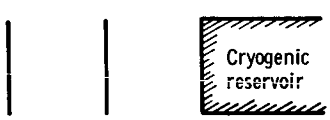
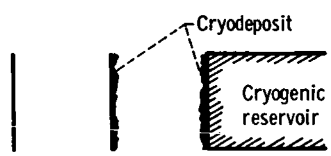


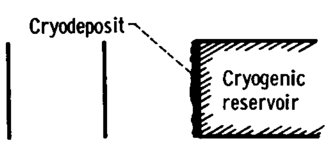
Figure 2. - Heat transport through 250° K H_2O deposit for 290° K blackbody radiation and solar radiation. $q_{tot} = (q_{cond} + q_{rad})/q_{rad\ incident}$.



Case 1. - No cryodeposits present. Incident flux, 0.14 W/cm^2; solar absorptance, 0.15 for first shield; emittance, 0.045; net boiloff flux, 2.68x10^{-4} W/cm^2; middle shield temperature, T_2, 272° K.



Case 2. - Deposit on inner shield and reservoir. Assumed emittance of deposit coated surfaces, 0.090; net boiloff flux, 3.52x10^{-4} W/cm^2; middle shield temperature, T_2, 246° K.



Case 3. - Deposit only on reservoir. Assumed reservoir emittance, 0.090; net boiloff flux, 3.50 W/cm^2; middle shield temperature, T_2, 268° K.

Figure 3. - Effect of cryodeposition on shadow shields.